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Procedia Materials Science 6 (2014) 1505 – 1510
Procedia Materials Science
www.elsevier.com/locate/procedia

3rd International Conference on Materials Processing and Characterization (ICMPC 2014)

Deformation Mechanism Analysis of Single Point Incremental Sheet Metal Forming

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Abstract

Single point incremental forming (SPIF) is a new innovative and feasible solution for the rapid prototyping and the manufacturing of small batch sheet parts. The process is carried out at room temperature and requires a CNC machining centre, a spherical headed tool and a simple support to fix the sheet being formed. In incremental Sheet Metal Forming the blank is incrementally deformed in to a desirable shape by hemispherical or ball nose tool traveling along a prescribed path. Due to the various advantages including the reduced production cost and time of prototypes, improved formability, easy modification of part design etc. the ISF is being popular as a new innovative forming technology. In the present study experiments were conducted to analyze the deformation mechanism of commercial aluminum alloy. Beside this analysis result of the effect of forming angle, step size, tool diameter on formability and wall thickness distribution are presented.

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Keywords: SPIF; Forming angle; Formability; Prototypes.

1. Introduction

During the past few years there has been increasing demand for the need of development of manufacturing technologies to handle with the market requirements, that is it should be also adaptable for new product development so that introduction of new products in the markets could be easily achieved. In most manufacturing industries, prototype manufacturing is an important step in the development or improvement of a product before proceeding to the manufacture of production.

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Selection and peer review under responsibility of the Gokaraju Rangaraju Institute of Engineering and Technology (GRIET)
doi:10.1016/j.mspro.2014.07.130

It allows a preliminary evaluation of the product during the design stage, and a reduction in the product development time. Incremental Sheet Forming (ISF) is an innovative forming approach for sheet materials. This process has been promising a flexible, short time, and inexpensive way to form sheet products. There are many different processes in metal forming that use an incremental approach.

With ISF approach, the deformation of the material is carried out incrementally and as a consequence, less forming loads are required comparing with the conventional processes.

The ISF technology is a forming approach which uses the CNC machining center, a spherical headed tool and a simple support to fix to produce a part from the sheet materials. The flexibility of the process is mainly related to the fact that SPIF does not require a dedicated die to operate as compared to other forming processes .ISF is a highly localized deformation process in which a tool, whose path is programmed to follow a particular trajectory, moves over a sheet metal and forms the desired shape. Three dimensional models of the part are designed using commercially available CAD/CAM software Feature CAM and CNC codes are generated by the same software. The codes are then fed into the CNC machine. As a result, the lead-time and cost of tooling along with the die cost can be avoided. This technique allows a relatively fast and cheap production of small series of sheet metal parts. Figure 1 gives the schematic representation of elements of ISF.

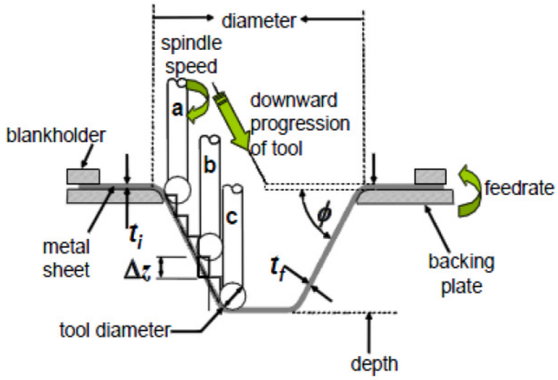

Fig. 1 ISF Process Terminology

2. Literature Review

The formability of sheet metal in incremental forming is different from that in conventional forming Freeform incremental forming is developed where two stylus tools are synchronized in motion and deform the sheet metal from opposite sides and they are traveling to form a product shape. M. Beatriz Silva, Martin Skjoedt given effect on the thickness distribution and position of strain points in the principal strain space. The strain paths are linear in the first stage and highly non-linear in the subsequent stages. The correlation between the experimental FLC and that resulting from the theoretical framework proposed by the authors is good and supports the claim that SPIF is limited by fracture instead of necking. J. Kopac and Z. Kampus given the priority to the movement of the tool starting in the centre of sheet metal and then restarting from the initial depth from the interior into exterior. And also concluded that the optimal inclination of walls on the product are 45°, bigger angles may cause errors, cracks, and product failure. Influential process parameters on the forming force (Fz) were presented by A. Petek, K. Kuzman, J. Kopae . The biggest deviation could be found by the variation of wall angle of forming, tool diameter and vertical step sizes of tool. M. Bambach, B. Taleb Araghi suggest that multi-stage forming strategies are an alternative to the over bending strategies. It was shown during forming; residual stresses are created in ISF that lead to geometrical deviations after trimming. Effect of process parameters—tool type, tool size, feed rate, friction at the interface between tool and sheet, plane- anisotropy of sheet—on the formability was investigated by Y.H. Kim, J.J. Park.

They concluded that, a little friction at the tool/sheet interface helps to improve the formability and the best formability was obtained with the 10 mm tool.

3. Experimental procedure

3.1 Plan of experiments

Experiments were performed to analyse effect of wall angle, step size, and tool diameter on formability of commercial AA8011. The spindle speeds of 1000 rpm and feed rate of 1500 mm/min were held constant throughout the experiments. All the parts were formed in a cone shape with a diameter of 94 mm and to achieve depth of 50 mm. Constant angle test were designed to evaluate the formability of material at an angle 55^0, 65^0 and 75^0. Multi angle test were designed to evaluate the maximum forming angles and depth achievement of the provided material. The continuous variation of angle form 35^0 to 90^0 along the conical profile. Following table 1 shows the variable parameter combination during the experiments.

Table 1. Plan of experiments

Constant Angle Test		
Tool Diameter	Wall angle (α) Degree	Step size (Δz) mm
6 mm	55	0.5
	65	0.5
	75	0.2
12 mm	55	0.5
	65	0.5
	75	0.2
Multi Angle Test		
6 mm	35 to 90	0.5

3.2 CAD/CAM design development

Conical shape were designed and drawn in one operation in order to investigate the ISF mechanism. CAD geometries were generated with UGNX CAD and contour tool paths were designed with UGNX CAM as shown in figure.2

a b

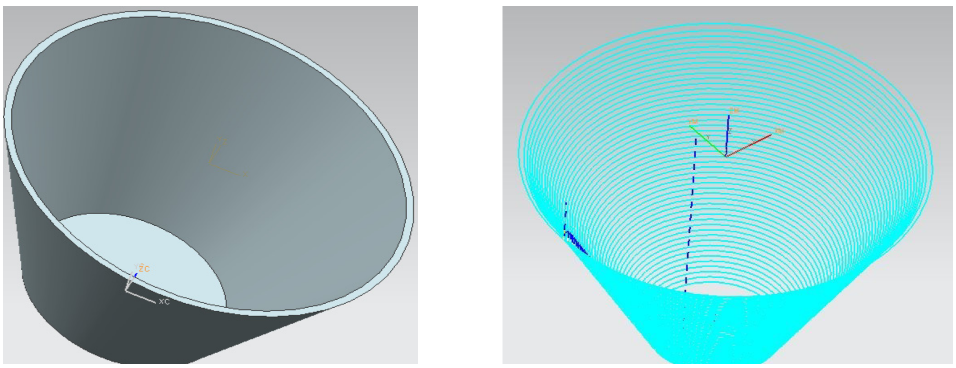

Fig. 2 a) CAD profile b) CAM tool path

3.3 Process description

The tests for the analysis of influential parameters at single point incremental sheet metal forming were carried out on 3 axis HAAS CNC Milling Machine. The machine tool is controlled by a computer and is programmed with a machine code system that enables it to be operated with minimal supervision and with a great deal of repeatability. The rod-shape forming tool with a smooth hemispherical head is clamped into the spindle of the milling machine. It was made of HSS which enables the forming of aluminum alloy materials as well as the stainless steel. The sheet metal is fixed and positioned with the upper blank holder, which is pressed onto the lower blank holder in which the simple die is placed. The whole support tool was inserted and fixed onto the worktable of the milling machine. While the punch presses and locally deforms the sheet directly under the punch head with a very small value of deformation, the blank holder and die remain fixed during the entire forming process. The punch follows to the predetermined tool path and gradually forms the sheet metal in a series of incremental steps until the final depth is reached.

The Step size (Δz) of single incremental sheet metal forming is shown in Figure 1. They are defined as 'x, 'z and h, representing increment in x and z direction and finite forming depth, respectively. It is evident from available literature that the lubricant between forming tool (punch) and specimen and between die radius and specimen is needed. For this reason the lubricant oil, which does not contain chlorine, was used

3.4 Material

Simple cone shape specimens were used for determination of material formability. Due to its frequent use in sheet metal forming industry, commercial AA 8011 were used as specimen material. Material properties are as follows: Young's modulus=72GPa, Density=2.71 g/cm^3, Poisson's ratio= 0.27, UTS=150MPa, Max. Elongation at fracture (%) = 50-60

4. Result and Discussion

4.1 Influence of wall angle (α)

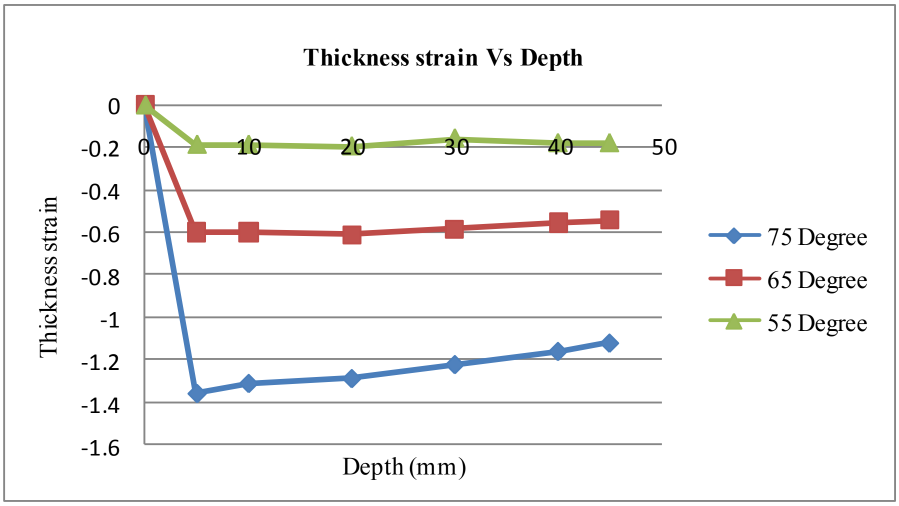

Fig. 3 Thickness strain Vs Depth of Cone for different forming angle

Experimentally it is observed that more thickness reduction can be achieved at larger wall angle but thickness distribution along wall is uniform for only for forming angle less than 65 degree. As wall angle increases deformation occurs due to stretching and local shearing. Due to stretching there is greater wall reduction near the top than near the bottom. Figure 3, gives us a clear indication of relation between the thickness reductions at different forming angle. The greatest achievement is that, the depth of 50 mm achieved without any crack near bottom.

Multi angle test were designed to evaluate the maximum forming angles of the AA8011 material. In multi angle test fracture occurred at 43.5mm depth.

4.2 Influence of vertical step size ((Δz)

Experiments were conducted to study the effect of step size (depth of increment Δz) on formability of sheet in ISF. The magnitude of the step down that the tool made after each pass is an important parameter which had an effect on limits of formability change from fracture to necking when other parameters were kept constant. During the study there was only one process. Vertical step size (Δz) varied while all other parameters remained unchanged Step size has noticeable effect on surface finish. As step size increases surface roughness also increases. Following figure 4 shows the surface finish for 0.2mm and 0.5mm step increment. For smaller step size local deformation plays an important role than stretching.

a b

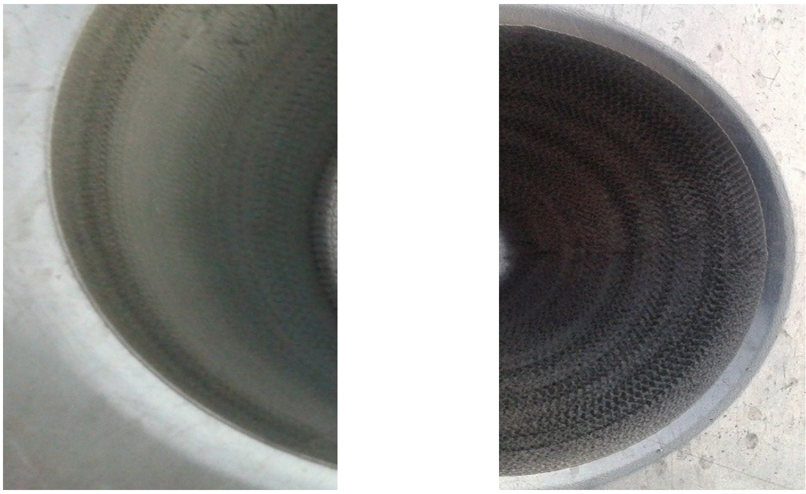

Fig. 4 a) Surface finish for 0.2 mm step size b) Surface finish for 0.5 mm step size

4.3 Influence of tool diameter

Tool size affects both the formability and the surface finish of the manufactured part through the process. Higher amount of forces generated when the tool diameter was changed form 6 mm to 12 mm. But vibrations produced due to 6mm diameter tool are more than the 12 mm diameter tool. Larger tools have a bigger contact zone and tend to support the sheet better during forming. Smaller tool diameter gives the better formability but up to certain limit. Higher formability seen with small radius tools is thought be a consequence of the concentration of force and strain as the surface area of contact is decreased at the tool tip If too small tool diameter (less than 6 mm) used formability will be decreases as it penetrates inside the sheet instead of causing uniform deformation.

4.4 Forming limit diagram in single point incremental forming

In sheet metal forming (SMF), forming limits are determined through the development of forming limit diagram. The circle grid analysis was utilized for FLC determination by taking the strain major true strain and minor true strain from the area localized just outside the neck. From the figure 5 it is concluded that the maximum forming angle of 75 degree can be achieved for the material AA8011.

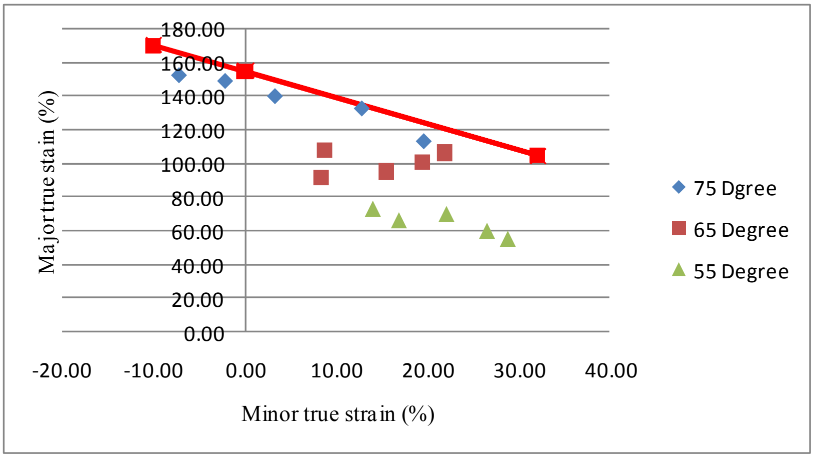

Fig. 5 Experimental Forming Limit Diagram for AA8011 in ISF

.5. Conclusion

1. The biggest deviation could be found by the variation of wall angle of forming. Greater formability and depth can be achieved for wall angle less than 75^0.
2. As the wall angle increases' stretching plays an important role in deformation than shearing. When wall angle decreases deformation is mainly takes place due to shearing.
3. With smaller vertical step forming forces decreases and larger depth can be achieved with better surface finish.
4. Tool size affects both the formability and the surface finish of the manufactured part.
5. Biaxial stretching at the corners and plain strain stretching at the sides produced. This is the reason crack occurred mostly at the corner.

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